Effect of Viscosity on Impedance Pump Performance

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Abstract — This study investigates the principle of impedance pump which made of an elastic tube filled with fluid that is connected at both ends to more rigid tube. The study show that the flow can be attained by introducing a periodic pinching applied at an asymmetrical location along the elastic tube. The effect of viscosity on impedance pump performance was experimentally investigated. The results show that as viscosity increases the mass flow rate through the pump decreases, while keeping the tapping frequency constant. The effective range for impedance pump operation was also identified.

Keywords— impedance pump, viscosity, flow rate

1. Introduction

The impedance pump principle can be demonstrated by using an elastic tube filled with fluid which connected at its ends to more rigid tubing of different impedance [1]. By periodically pinching the elastic tube with an active element at an asymmetric position relative to its ends, a complex series of waves is produced. Traveling waves emitted from the compression of the elastic tube will combine with reflected waves at the impedance-mismatched positions. As the result of these wave dynamics, a net flow in a specific direction is observed. The impedance pump develops the net flow by imparting the kinetic energy from the compression of the elastic tube and transmitting that energy into the fluid through surface waves [2].

1.1. Impedance Pump Mechanism

The impedance pump consists of an elastic tube which functions as compressible section and connected at both ends to a more rigid tube with different impedance. The compression section is suitable for any material that allowing for wave propagation because impedance based pumping depends on wave reflection. Impedance mismatch is created by connecting the elastic tube at both ends to another materials with different mechanical and geometries properties and therefore will generate the net flow. Figure 1 below shows a schematic of different impedance which represented by $Z_0$ and $Z_1$.

![Fig. 1 A schematic of an impedance pump. The impedances are represented by $Z_0$ and $Z_1$. The two arrows show the pinch location [3].](image)

The pinch location is the fundamental principle of the impedance pump mechanism. The pinch location must be asymmetrically from the center of the elastic tube in order to produce a flow. Periodic pinching at an offset center location results in a pressure builds up from wave interference and generate a flow. The direction of flow inside the tube can be reversed by changing pinch location, frequency and duty cycle [3].

2. Methodology

An experimental approach was chosen to investigate the impedance pump’s behavior. The objective of the experiment is to identify the best range of fluid viscosity that impedance pump can operate effectively. This project also involves the modeling of experiment setup to examine the behavior of the impedance pump using different fluid viscosity. There are several data to be taken from the experiment in order to obtain the result.

2.1. Experiments

Experiments are conducted to investigate the effect of viscosity on impedance pump. All experiments were done in a controlled room temperature approximately 28°C. The volume inside the setup is kept constant for every experiment with tapping frequency at 5 Hz.

![Fig. 2 The experiment setup of impedance pump](image)

Impedance pump consist of elastic tube, rigid tube and actuator as the main components as shown in the Fig 2. The elastic part made of a latex tube with thickness of 0.4 mm and length of 0.15 m was used for the closed loop model. Another PVC tube, with diameter 0.077 m and length 0.8 m was used as the rigid tube. While the actuator was carried out using a direct current (DC) motor with a metal rod attached at the tip. An alternating current (AC) was supplied to the DC motor with adjustable frequency causing the metal rod to oscillate back and forth continuously using the function generator as shown in the Fig. 3a. Function generator used to generate sinusoidal function which allows the pincher to move back and forth continuously. To improve the frequency and amplitude of the actuator, amplifier was introduced to the system as shown in the Fig 3b. This mechanism was observed to be a reliable way to power the pump in the closed loop model.

![Fig. 3a The function generator](image) ![Fig. 3b The amplifier](image)

The effect of the fluid viscosity is tested using eleven different water-glycerol mixtures. The viscosity is adjusted by adding the percentage of glycerol inside the water solution. The eleven solutions are water with 0% volume glycerol, a 10% volume glycerol, 20% volume glycerol until 100% volume glycerol with 0% volume water. Stop watch is used to measure the time needed for the tracer inside the setup to complete one revolution.

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3. Results

Table 1 shows the data collected from the viscosity experiment through the impedance pump with constant tapping frequency 5 Hz at 28°C. The viscosity of the solution was converted from percentage of glycerol to viscosity value in centipoise (cP) based on data in the Viscosity of Aqueous Glycerine Solutions table [4].

Table 1. Experiment result for viscosity

<table>
<thead>
<tr>
<th>Viscosity, ν</th>
<th>Density, ρ (kg/m³)</th>
<th>Area, A (m²)</th>
<th>Velocity, v (m/s)</th>
<th>Mass Flow Rate, ṁ (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>cP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.84</td>
<td>1000</td>
<td>0.0047</td>
<td>0.106</td>
</tr>
<tr>
<td>10</td>
<td>1.09</td>
<td>1101</td>
<td>0.0047</td>
<td>0.086</td>
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<tr>
<td>20</td>
<td>1.35</td>
<td>1127</td>
<td>0.0047</td>
<td>0.073</td>
</tr>
<tr>
<td>30</td>
<td>2.05</td>
<td>1145</td>
<td>0.0047</td>
<td>0.056</td>
</tr>
<tr>
<td>40</td>
<td>2.92</td>
<td>1177</td>
<td>0.0047</td>
<td>0.043</td>
</tr>
<tr>
<td>50</td>
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<td>1200</td>
<td>0.0047</td>
<td>0.032</td>
</tr>
<tr>
<td>60</td>
<td>7.91</td>
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</tr>
<tr>
<td>70</td>
<td>15.78</td>
<td>1233</td>
<td>0.0047</td>
<td>0.0056</td>
</tr>
<tr>
<td>80</td>
<td>39.14</td>
<td>1247</td>
<td>0.0047</td>
<td>0.0033</td>
</tr>
<tr>
<td>90</td>
<td>131.03</td>
<td>1262</td>
<td>0.0047</td>
<td>0.0019</td>
</tr>
<tr>
<td>100</td>
<td>771.62</td>
<td>1315</td>
<td>0.0047</td>
<td>0.0011</td>
</tr>
</tbody>
</table>

Density of the solution, area of the tube and velocity of the solution are used to calculate the mass flow rate of the fluid.

\[
ṁ = ρ A v
\]  

where \( \dot{m} \) is mass flow rate  
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\( A \) is area of the tube  
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Fig. 4 shows the effect of viscosity on the mass flow rate through the impedance pump with constant tapping frequency 5 Hz. Glycerol solutions with different fractions of glycerol to water were used to investigate the effects of viscosity on the performance of impedance pump. The solutions tested were 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% volume glycerol by mass corresponding to relative viscosities of 0.84 cP, 1.09 cP, 1.35 cP, 2.05 cP, 2.92 cP, 4.57 cP, 7.91 cP, 15.78 cP, 39.14 cP, 131.03 cP and 771.62 cP respectively.

4. Discussions

The results in Fig. 4 show that as viscosity increases the mass flow rate of glycerol-water solution through the pump decreases, while keeping the tapping frequency constant at 5 Hz. The mass flow rate consistently decreases from 0% to 70% volume glycerol solution with average of 0.066 kg/s. However, from 70% to 100% volume glycerol shows a very small decrease of mass flow rate with average of 0.008 kg/s. Small change in mass flow rate indicates the higher time needed for impedance pump to perform its application.

Therefore, the best range that impedance pump can operate effectively is from 0% volume glycerol which is 0.84 cP until 70% volume glycerol which is 15.78 cP. Every fluid with the viscosity within this range, 0.84 – 15.78 cP is suitable for impedance pump. It also can be concluded that gasoline (0.5 cP), water (1.0 cP), methanol (0.6 cP), ethanol (1.2 cP), mercury (1.5 cP) and milk (3.0 cP) are suitable as the working fluid for impedance pump.

This range gives people a better understanding on the fluid viscosity that supposed to use for impedance pump. This result also gives people a new perspective of impedance pump and leads to a new application in fluid transportation field.

5. Conclusions

The impedance pump can be demonstrated by an elastic tube filled with fluid and connected at its ends to more rigid tube of different impedance. By periodically pinching the elastic tube with an active element at an asymmetric position relative to its ends, a complex series of waves is developed. Presented in this study are the experimental results of the viscosity effects on the impedance pump performance. The experimental results show that the impedance pump was capable to pumping the fluid effectively within a certain range of fluid viscosity. The results indicate that as viscosity increases the mass flow rate through the pump decreases, while keeping the tapping frequency constant at 5 Hz. The mass flow rate is consistently decreases as the fluid viscosity increases from 0% to 70% volume glycerol solution. However, the mass flow rate shows a small change from 70% to 100% volume glycerol solution. Therefore, the best range that impedance can operate effectively is from 0% volume glycerol which is 0.84 cP until 70% volume glycerol which is 15.78 cP. Every fluid with the viscosity within this range, 0.84 – 15.78 cP is suitable for impedance pump.

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References